Competency 2.12 **Radiation protection personnel shall demonstrate a familiarity level knowledge of the Department's guidance for the structure, function, and operations of a radiation-generating device (RGD) control program.**

- **Implementation Guide G-10 CFR 835/C3-Rev.2, *Radiation Generating Devices***
- **10 CFR 34, *Licenses for Radiography and Radiation Safety Requirements for Radiographic Operations***

1. SUPPORTING KNOWLEDGE AND /OR SKILLS

a. Describe the different types of radiation-generating devices that may be used at a DOE site:
   - X-ray machines
   - Accelerators
   - Irradiators
   - Radiography sources

b. Using Implementation Guide G-10 CFR 835/C3-Rev. 2, *Radiation Generating Devices*, discuss the differences between an open beam and cabinet x-ray system and the different types of controls (design, equipment, and administrative) that can be used to prevent radiation exposure above DOE limits.

c. Discuss possible exposure incidents (or ones that have actually happened in private industry) as a result of improper practices with accelerators, irradiators, and radiography sources, or loss of radiography sources.

d. Discuss possible actions to control sources on a DOE site, especially radiography sources brought on DOE sites by subcontractors who may be unaware of the site radiation protection program (RPP) and 10 CFR 835, *Occupational Radiation Protection,* since their source most likely is licensed by the Nuclear Regulatory Commission (NRC) under 10 CFR 34, *Licenses for Radiography and Radiation Safety Requirements for Radiographic Operations,* which requires the licensee (i.e., the subcontractor) to follow 10 CFR 20, *Standards for Protection Against Radiation,* for their RPP (or the state equivalent, if the source is licensed by an agreement state).

2. SUMMARY

DOE/EH-0256T (Revision 1), *Radiological Control Manual*, directs that all site-specific radiation control manuals contain provisions for the types of radiation-generating devices (RGDs) found at those sites. The *Radiological Control Manual* further directs that DOE Order 5480.4, *Environmental Protection, Safety and Health Protection Standards*, be used for meeting the intent of the manual. DOE Order 5480.4, in turn, mandates the use of American National Standards Institute's (ANSI) N 543-1974, *General Safety Standard for Installations Using Non-Medical X-Ray and Sealed Gamma Ray Sources Energies Up to 10 MeV*; ANSI N 43.2-1988, *Radiation Safety for X-Ray Diffraction and Fluorescence Analysis Equipment*; and 10 CFR 34, *Licenses for Radiography and Radiation Safety Requirements for Radiographic Operations*, for meeting its requirements covering RGDs.

RGDs are not precisely defined in the *Radiological Control Manual*; however, Implementation Guide (IG), G-10 CFR 835/C3 (Revision 1), *Radiation-Generating Devices*, defines RGDs as "a collective term for devices that produce ionizing radiation, sealed sources that emit ionizing radiation, small particle accelerators used for single purpose applications that produce ionizing radiation (e.g., radiography), and electron-generating devices that produce x-rays incidentally."

G-10 CFR 835/C3 (Revision 1) can be found in its entirety on the following web site:

http://tis-nt.eh.doe.gov/wpphm/regs/regs.htm

Excerpt from Implementation Guide for use with Title 10, Code of Federal Regulation, Part 835 (G-10 CFR 835/C3 - Rev.1), *Radiation Generating Devices*

Section IV, Subsection D - Engineered Safety Controls

D. Engineered Safety Controls

RGD installations "shall" be designed so that radiation protection is achieved primarily through physical controls, and secondarily through administrative controls (10 CFR 835.1001 and *Radiological Control Manual* [RCM] 311). ANSI N43.3 and N43.2 describe specific requirements for exempt shielded (including cabinet x-ray), shielded, unattended, and open installations. As discussed in Section IV.B.2, RGD Installation Design, of this IG, not all of the ANSI requirements for shielded, unattended, and open installations meet the requirements of 10 CFR 835. As a consequence, the design of any new RGD installation or modification of existing ones requires the use of installation designs that provide adequate inherent shielding to meet the radiological exposure levels discussed in Section IV.B.2, RGD Installation Design of this IG. The alternative is the implementation of additional access and occupancy controls to meet the design objectives.

Section IV.D.1, Shielding, Controls, & Safety Devices of this IG, describes requirements for engineered (i.e., physical) safety controls that are common to RGD installations. Specific criteria for each installation type are provided in Section IV.D.2, Requirements for Specific RGD Installations of this IG.

Requirements for engineered controls provided in this Section should be considered in conjunction with requirements discussed in Section IV.B, Development of Site-Specific Documents of this IG.

1. Shielding, Controls, & Safety Devices

RGD installations "shall" (10 CFR 835.100 [a] and RCM 311) include, as essential measures, the following engineered safety controls:

a. Shielding

Shielding should be of assured quality, uniformity, and permanency to attenuate radiation levels outside the enclosure of exempt shielded, shielded, and unattended installations. Lead shielding shall be mounted so that it does not cold-flow because of its weight and to be protected from mechanical damage (ANSI N43.3[7.2.1]). Joints between similar or different shielding materials shall be constructed so that the overall protection of the shield is not reduced (ANSI N43.3 [7.2.2], [7.3.1], and [7.3.2]).

The following aspects of installed shielding should be considered to ensure proper documentation and consideration of ANSI N43.3 (Sections 6 & 7); as well as Appendices A, B, C, and D:

- The thickness and type of shielding material, the arrangement of the shielding material and devices, the locations of concrete used for shielding, as well as the density and uniformity of the concrete aggregate determined from samples cast during construction
- The specified dimensions of shielding barriers or baffles
- The degree of overlap of primary shielding or between primary shielding and other shielding or barrier materials
- The shielding behind electric boxes and lock assemblies
- The locations of shielded viewing windows, and the thickness and densities thereof
- The locations and dimensions of penetrations in the shielding walls and doors

Penetrations of the primary shielding to permit the passage of vents, pipes, ducts, or cables shall also be shielded or baffled (ANSI N43.3[7.4]).

The effect of temporary shielding should be evaluated prior to its installation. The installation, use, and removal of temporary shielding should be controlled by procedures and in accordance with RCM 314.

b. Access Control and Safety Devices

The purpose of the access control devices is to prevent entry into a radiological area and/or to warn of a hazard.

The RCM (Appendix 3B) specifies that one or more of the following features should be used for each entrance or access point to a high radiation area and "shall" (10 CFR 835.502[a] and RCM, Appendix 3B) be used for each entrance or access point to a high radiation area where radiation levels exist such that a person could exceed a whole body dose of 1 rem (0.01 Sv) in any one hour:

(1) A control device that prevents entry to the area when high radiation levels exist or upon entry causes the radiation level to be reduced below that level defining a high radiation area;
(2) a device that functions automatically to prevent use or operation of the radiation source or field while individuals are in the area;

(3) a control device that energizes a conspicuous visible or audible alarm signal so that the person entering the high radiation area and the supervisor of the activity are made aware of the entry (**Note**: Administrative procedures "shall" define the required actions of personnel when alarms are activated to demonstrate compliance with 10 CFR 835.501[d] and RCM 334);
(4) entryways that are locked, except during periods when access to the area is required, with positive control over each entry;
(5) continuous direct or electronic surveillance that is capable of preventing unauthorized entry; and
(6) a control device that automatically generates both audible and visual alarm signals to alert personnel in the area before use or operation of the radiation source and in sufficient time to permit evacuation of the area or activation of secondary control devices to prevent use or operation of the source.

Of all the access control options specified above, Subparagraph (2), is preferred because the device directly controls the source of radiation. The selection and implementation of subparagraph options (1), (3), or (6) should require the review and approval of the radiation protection manager and the cognizant operations organization.

If locked entryways are used, the keys used for one RGD installation or storage facility should not provide access to another RGD installation or storage facility.

Additional measures "shall" (10 CFR 835.502[b]) and RCM Appendix 3B) be implemented to ensure individuals are not able to gain access to very high radiation areas when dose rates are in excess of the posting requirements of 10 CFR 835.603(c) or RCM Table 2-3. Such measures (i.e., physical constraints) include locking or securing service doors and panels with tamper resistant fasteners (ANSI N43.3[5.2.2.4]), or the use of multiple and redundant access controls.

Additional requirements that apply to shielded installations are specified in Section IV.D.2.b., Shielded Installations, of this IG.

Due to the lack of intrinsic shielding and the nature of use, access to a very high radiation area could be possible for a "open" installation. Additional measures (e.g., interlocked "photoelectric eye" light beams) should be established to meet this requirement.

Physical access controls over radiological areas "shall" (10 CFR 835.501[e] & 502[c]; RCM Appendix 3B.3; ANSI N43.3[5.1.4]) be established in such a way that does not prevent a person from rapidly evacuating the area.

c. Interlocks

To implement the requirement of 10 CFR 835.502(a)(1) thru (3) and RCM Appendix 3B.1(a-c), the device must be interlocked to provide a safe or fail-safe condition to maintain exposures ALARA. Doors and/or access panels in exempt shielded, shielded, and unattended installations shall be equipped with one or more fail-safe safety interlocks to prevent irradiation of an individual (ANSI N43.3[6.5.2]).

If an area radiation monitor is incorporated into a safety interlock system, the circuitry shall be such that a failure of the monitor shall either prevent normal access into the area or operation of the RGD (RCM 553.6)

Additional requirements that apply to shielded installations are specified in Section IV.D.2.b., Shielded Installations, of this IG.

Current, as-built schematic diagrams (mechanical and electrical) of safety interlocks shall be maintained by, or available to, the RGD custodian (see Section IV.C.9.c., RGD Specific Records of this IG)(10 CFR 835.1001[a] and RCM 311).

d. Device Controls

One or more physical control devices should be used to secure the RGD to prevent unauthorized access and use. The control system governing the production of radiation should be equipped with a lock and key to prevent unauthorized use. The key controlling the production of radiation in one RGD should not control the production in another.

Control devices used to limit RGD time, position (irradiation geometry), current, voltage, beam intensity, or control panel lights or system indicators shall be fail-safe to demonstrate the "proper operation" required by ANSI N43.3(7.6.2) and ANSI N43.2(5.2.2.1.4.). If used for individual safety, these devices "shall" (10 CFR 835.501[d] and RCM 334) be inspected and checked. Recommended inspection frequencies are specified in Appendix B of this IG.

e. Run-Safe and Emergency Shutdown Devices

Administrative procedures "shall" (10 CFR 835.501[d] and RCM 334) be implemented to ensure that the RGD installation and the RGD safety interlock control devices are such that:

- Radiation cannot be produced until the interlock system logic has been completely satisfied.
- Production of radiation cannot be resumed by merely reestablishing the interlock circuit at the location where an interlock was tripped.
- The safety circuit shall be re-energized or reestablished manually (preferably the safety circuit reset is on or near the main control console). See Section IV.D.2.b, Shielded Installations, for emergency shutdown requirements.

f. Warning Devices

For each area designated as a high-radiation area or very high-radiation area, 10 CFR 835.502 and the RCM (Appendix 3B) provide an option that permits a control device to automatically generate audible or visible alarm signals to alert individuals and the cognizant RGD custodian of a potential entry into the area before it occurs. In order to meet ANSI N43.3 requirements, warning devices shall be provided as an addition to any other access control feature in accordance with the installation specific requirements delineated in Section IV.D.2, Requirements for Specific RGD Installations, of this IG. These warning devices are typically warning lights.

All RGD warning lights should be red for consistency (ANSI N43.5(6.2.1)). A sufficient number of lights should be installed so that at least one light is easily visible from all reasonably occupied areas and from reasonable avenues of approach to such areas.

However, warning lights (even though interlocked to fail-safe, if burnt out) are only passive in nature. When operating, they generally do not prevent an individual from physical access to a radiation beam unless they are used as part of a photosensitive circuit. Such a circuit would remove the radiation beam or field if any individual intercepted the light beam.

Due to the passiveness (i.e., reliance on worker attention and action) of this safety feature and the potential for failure, at least one interlocked warning light should be used in all circumstances. The interlocked warning light should be used to provide "visual indication" that radiation is being produced, and should be used in conjunction with any interlocked safety device which restricts physical access to a radiation beam or field. This is recommended

above and beyond the installation specific requirements in Section IV.D.2 of this IG, or the minimum required by 10 CFR 835.502. When used in this fashion, the RGD shall not be operable when the warning light is out (ANSI N43.3[5.1.3], [5.1.5], & [8.6.2] and ANSI N43.2[5.2.2.1.4]).

It should not be possible to override the operation of any warning device activated by a fail-safe function without positive actions by the operator such as resetting controls at the control console (see Section IV.D.1.e., Run-Safe and Emergency Shutdown Devices, of this IG).

g. Monitoring Instruments

Requirements for instruments used to measure radiation are given in 10 CFR 835.401(c) and RCM 551, 553, and 562.

2. Requirements for Specific RGD Installations

In addition to the general requirements in Section IV.D.1, of this IG, there are specific requirements cited from ANSI N43.3 and N43.2 for each of the primary RGD installations and the open- and shielded- beam analytical RGDs. The analytical RGD installations may enclose one or more x-ray devices and/or sealed radioactive sources.

The ANSI standards specify dose rates that are to be used for installation categorization only and are not to be interpreted as permissible levels.

The following requirements are specific for each installation or RGD type.

a. Exempt Shielded Installations

Requirements for exempt shielded installations are:

- The RGD and all objects exposed to the source of radiation shall be within a permanent enclosure which, under all circumstances of use, possesses sufficient inherent shielding to meet the following dose rate limit (ANSI N43.3[4.1.1]).
- The exposure at any accessible region 2 inches (5 cm) from the outside surface of the enclosure shall not exceed 0.5 mrem (5 μSv) in any 1 hour ANSI N43.3 (4.1.1).
- The requirements as cited in ANSI N43.3(4.1.1) and (5.1.10).

b. Shielded Installations

Requirements for shielded installations are:

- The RGD and all objects exposed to the source are within a permanent enclosure from which persons are excluded during the irradiation (ANSI N43.3[5.1.1]).
- Interlocks shall be provided to prevent personnel access and audible or visible warning signals shall be provided within the enclosure (ANSI N43.3[5.1.2] and [5.1.3]). In lieu of the audible or visible signal, ANSI N43.3(5.1.3.3.) permits the use of two interlocks (at minimum) to prevent personnel access to x-ray installations.
- For any RGD that produces a radiation level in excess of 500 rads/h at 1 meter (or 500 R/h at 3 feet), both audible and visible warning signals are required (10 CFR 835.502[b], RCM 334.2, and ANSI N43.3[5.1.5]) (**NOTE**: This does not apply to installations where personnel access into the very high radiation areas is not possible).
- At least one or more "emergency shutdown buttons" shall be installed inside the shielded enclosure (if humanly occupiable) of the installation in conspicuous locations that are easily and directly accessable to allow rapid activation in the event of an emergency. The shutdown device shall provide an effective means of quickly interrupting the RGD operational sequence prior to or during production of the useful beam or during the movement of an RGD from a shielded to unshielded position (ANSI N43.3[5.1.5.2]) . See Section IV.C.7, Labeling, of this IG for labeling requirements.
- When entering the exposure area, enclosure, or room after irradiation, the operator shall use a survey meter to verify that a sealed radioactive source has been returned to its shielded storage location or that radiation is no longer being produced by the RGD (RCM 334.5 and 552.1.c.; and ANSI N43.3[9.3.1.5]).
- If the installation is of the walk-in type, a prominently posted sign inside the exposure room should read:

"WHEN WARNING SIGNAL IS ON, VACATE ROOM IMMEDIATELY"

where such warning devices are installed.
Another sign posted at the entrance should read:

"CAUTION ENTERING A RADIATION EXPOSURE ROOM
DO NOT ENTER WHEN WARNING SIGNAL IS ON"

Also, other requirements cited in ANSI N43.3(5.1 and 9.3.1) should be met.
For any installation that is being operated as an irradiator facility under the jurisdiction of a NRC license, Subpart C of 10 CFR 36, *Licenses and Radiation Safety Requirements for Irradiators* (NRC, 1993) provides additional design and performance requirements.

c. Unattended Installation

Requirements for unattended installations are:

- That the RGD is installed in a single-purpose shielded enclosure (ANSI N43.3[5.2.1.1])
- The other requirements cited in ANSI N43.3(4.2) and (5.2)

The design shall ensure that individuals are not exposed to doses exceeding 100 mrem (1 mSv) in a year. If it is not possible to demonstrate that an individual receives less than this limit and occupancy rates in the vicinity of the installation are known to be low, a short-term limit of 2 mrem (0.02 mSv) in any 1 hour may be used provided that a radiation survey or monitoring device shows that the expected dose to an individual is less than 100 mrem (1 mSv) per year (ANSI N43.3[5.2]).

d. Open Installation

Requirements for open installations are:

- A conspicuously posted and defined perimeter, visible from any approach, that limits the area in which the exposure can exceed 5 mrem (0.05 mSv) in any 1 hour (ANSI N43.3 [5.3.3]). The posting should be in accordance with Section IV.C.6.a, Radiation Area, of this IG.
- A conspicuously posted and defined perimeter, visible from any approach, that limits the area in which the exposure can be or exceed 100 mrem (1 mSv) in any 1 hour (ANSI N43.3[5.3.1]). The posting should be in accordance Section IV.C.6. b, High-Radiation Area, of this IG.
- A conspicuously posted and defined perimeter, visible from any approach, for a potential very high-radiation area, where the "additional control measures" apply as required by Section IV.D.1 (b), Access Control and Safety Devices, of this IG.
- The operational staff "shall" provide constant surveillance to ensure that no person has physical access to the high-radiation or very high-radiation area within the perimeter or remain in the area during the irradiation and operation of the RGD (ANSI N43.3[5.3.4]).

- RGD source and equipment essential to use shall be attended by a knowledgeable person or kept in a locked enclosure to ensure that the RGD is not used by unauthorized individuals, tampered with, or removed (RCM 431 and ANSI N43.3[5.3.4]).
- The performance of radiation surveys to define the boundaries specified above (10 CFR 835.401, RCM 551, and ANSI N43.3[5.3]);
- When entering the operating area after irradiation, the operator "shall" use a survey meter to verify that a radioactive source has been returned to its storage location or that radiation is no longer being produced (10 CFR 835.501[d] and 401[a][5], 10 CFR 34.43[b], RCM 334.5 and 552.1.c., and ANSI N43.3[9.3.3.3.1]).
- Temporary shielding should be used in accordance with RCM 314.
- All individuals "shall" wear a primary whole-body dosimeter (10 CFR 835.402[a][1][i] and RCM 511.1.a).
- All individuals shall wear supplemental dosimeters (a direct reading and alarming dosimeter) in addition to the primary dosimeter (10 CFR 34.33, ANSI N43.3[9.4.2] & [9.4.3] and RCM 513).
- Extremity dosimeters "shall" also be used where potential doses to the extremities may be 5 rems (0.05 Sv) or greater in a year (10 CFR 835.402[a][1][ii] and RCM 511.1.a).
- The other requirements as cited in ANSI N43.3(5.3) and (9.3.3).
- All radiography using by-product material as a sealed radioactive source (and not under an NRC license) should be conducted in accordance with 10 CFR 34 as modified by the site-specific RCM or RPP and this IG for onsite operations at DOE facilities.
- All radiography conducted by offsite contractors at DOE facilities shall be conducted in accordance with RCM 431.9 4 and 10 CFR 34 or equivalent Agreement State requirements (RCM 365.5), and the degree of onsite oversight shall be determined by the onsite radiation protection manager.

e. Analytical Devices: Enclosed Beam Installations

In this subclass of installation, the radiation source, sample and detector (if used) are enclosed in an exempt shielded enclosure or chamber that prevents inadvertent entry of any part of the body during normal operations. The inherent shielding and access controls for these devices allow activities in close proximity to the device while the beam is activated. It is not uncommon for several of these devices to be operated in the same room. Requirements for warning devices, interlocks, etc., are similar to those used for the exempt shielded (cabinet-type) installations and those requirements for the engineered controls. Additional requirements are cited in ANSI N43.2(5.2.2.1) & (5.2.2.3).

f. Analytical X-Ray Devices: Open-Beam Installations

In this subclass of installation, the sample to be analyzed cannot be enclosed in a exempt shielded chamber or enclosure. A shutter controls the presence of the radiation beam. The shutter is opened after the operator leaves the room or moves to a safe distance behind barriers or shielding.

Requirements are similar to a shielded installation. A system barrier for the operators should be part of the installation to prevent inadvertent access to the RGD during normal operations (ANSI N43.2[5.2.2.2.6]). The barrier should have sufficient inherent shielding so that the exposure received by any individual does not exceed the design criteria specified in Section IV.B.2., RGD Installation Design, of this IG. Additional requirements for this type installation are cited in ANSI N43.2(5.2.2.1 & .2).

g. Particle Accelerators

Small (low voltage, less than or equal to 10 MeV) particle accelerators used for radiography, ion implantation, or the production of incidental photons or particles (e.g., neutron generators) in exempt shielded, shielded, or open installations are subject to the requirements specified by this IG and the applicable ANSI standards. When accelerators are used outside of exempt shielded or shielded installations, requirements for open-air radiography prevail. When used within shielded installations, determination must be made whether the requirements for the exempt shielded or shielded installations prevail. Although the basic RPP requirements discussed in this guide are generally applicable to the large multi-purpose research accelerators, the complexities associated with these facilities may require additional consideration beyond the scope of this guide. Additional requirements for those RGDs with particle energies exceeding 10 MeV are provided in DOE Order 5480.25, *Safety of Accelerator Facilities* (DOE, 1992c).

For any accelerator which produces neutrons (e.g., proton or deuteron particle generator using a tritium target), procedures "shall" also address contamination control and monitoring (10 CFR 835.404 and RCM 337).

h. Electron Devices that Generate X-Rays Incidentally

These devices are usually shielded to attenuate the emission of x-rays. Requirements for the exempt shielded or shielded installations prevail. Examples include electron beam welders, electronic microscopes, pulse generators, etc., and microwave cavities if used as beam guides. Preoperational inspections and surveys should be performed initially upon receipt. However,

the requirement for the routine semiannual inspections and surveys may be modified at the discretion of the radiation protection manager. Inspections and surveys should be performed after any modification. In the absence of modifications, the radiation protection staff "shall" conduct independent inspections and surveys (10 CFR 835.401[a][5] & 501[d] and RCM 551.4).

i. Cabinet X-Ray Systems

Since these RGDs are used primarily in security applications and are commercially available, manufacturer requirements for these RGDs are delineated in 21 CFR Part 1020.40. These RGDs shall be procured, categorized, inventoried, operated, inspected and surveyed, and decommissioned in accordance with the requirements of this IG to ensure compliance with 10 CFR 835.1001 & 1003 and RCM 311. Inspections and surveys should be performed as specified in section IV.D.2.h., Electron Devices that Generate X-Rays Incidentally, of this IG.

If not commercially obtained, the requirements for an exempt shielded installation prevail.

ANSI N 43.2-1988, *Radiation Safety for X-Ray Diffraction and Fluorescence Analysis Equipment*, applies to x-ray diffraction and fluorescence analysis equipment, and fluorescence analysis equipment using radioactive material. These devices are also known as analytical equipment. This standard reviews the types of injuries resulting from accidental exposure to ionizing radiation from these devices, establishes design criteria, sets up requirements for operating procedures, and recommends personnel monitoring programs.

X-ray diffraction units and x-ray fluorescence analysis equipment both generate high-intensity ionizing radiation that can cause severe and permanent injury to any part of the body that is exposed to the primary beam. Most of the accidental overexposures from industrial x-ray sources have involved analytical equipment. Fingers and eyes are the most common body parts exposed during accidents, and exposures have resulted in amputations and cataracts.

ANSI N 43.2 recognizes two classes of x-ray systems, enclosed-beam systems and open-beam systems. Both types are required to have a beam trap, visible signal of x-ray production at the exposure switch as well as at the source housing, and a fail-safe interlock for x-ray tube disassembly. Operating procedures and beam alignment procedures shall be documented by the manufacturer and followed by the users. Alignment procedures should be designed so that hands and eyes receive less than a specified amount of radiation exposure. The open-beam units are typically more hazardous than the enclosed beam systems. The open-beam systems are required to have shutters with fail-safe design, and shutters on all ports interlocked with the collimator coupling. A guard or interlock should be used to prevent entry of body parts to the primary beam. The enclosed systems are required to have a chamber interlocked with the high voltage generator so that no x-rays are produced with the chamber open.

Most injuries occur during nonroutine repair and alignment. The users should operate the equipment according to the manufacturer's specifications, and follow the manufacturer's recommended alignment procedures. If modifications are necessary, the radiation protection organization must approve the changes. Also, nonstandard accessories should not be aligned until procedures have been approved. All users and maintenance personnel should be cautioned to not remove covers, shielding materials, or tube housings; or make modifications to shutters, collimators, or beam stops until the beam is off.

The purpose of ANSI N 43.3-1993, *General Safety Standard for Installations Using Non-Medical X-Ray and Sealed Gamma Ray Sources Energies Up to 10 MeV*, is to keep radiation exposures As Low As Reasonably Achievable (ALARA) due to the wide variety of x-ray and sealed gamma ray sources that are used extensively in industry for the inspection, testing, and analysis of materials.

The standard classifies installations into five types: shielded installations, exempt shielded installations, certified cabinet x-ray systems, unattended installations, and open installations. The requirements in the standard are specific to the type of installation since some installations are inherently less hazardous due to their design. The two types of installations where radiation exposures are most likely to occur are open installations (e.g., mobile x-ray radiography and/or gamma ray radiography that takes place in open areas) or shielded installations (e.g., large, fixed x-ray, or gamma ray machines in a shielded room). The standard contains requirements for interlocks, audible and visual signals of radiation while it is being emitted, posting of warning signs, and permissible exposure levels. Safety devices (i.e., shutters, lights, and interlocks) are required to be of fail-safe design, which means that if a safety device, like an interlock, fails, exposure is prevented. The safety devices such as shutters, lights, and interlocks are to be tested at least every six months. Many accidental exposures have occurred over the years because workers, attempting to increase production and throughput, intentionally bypass the interlocks by taping down the microswitches.

The standard also addresses shielding design surrounding these types of sources. Included are recommendations for maintaining shielding effectiveness when conduits, doors, or windows penetrate shielded walls. The appendices contain useful data for calculating shielding thicknesses for gamma ray sources as well as x-ray sources.

10 CFR 34, *Licenses for Radiography and Radiation Safety Requirements for Radiographic Operations*, applies only to sealed gamma ray sources used in radiography by the Nuclear Regulatory Commission (NRC) or NRC Agreement State licensees. It is not a mandatory standard for adoption by DOE facilities. Some of the requirements in this NRC regulation are for exposure devices, such as coupling the source to the drive cable, labeling the source capsule and exposure device, locking the exposure device when not in use, and physically securing the exposure device during transport or storage. Other requirements include leak-testing the source every six months, performing radiation surveys at various stages of radiography, calibrating survey instruments every three months, performing a quarterly inventory of sources, and adhering to requirements for operating and emergency procedures. In 10 CFR 34, three types of personnel monitoring are required: a whole-

body film badge or thermoluminescent dosimeter (TLD), a pocket ionization chamber, and an alarming ratemeter. The most frequent cause of accidental exposures (at least among NRC or Agreement State licensees) is a failure of the radiographer to perform surveys, which has resulted in exposures from sources that were left in the unshielded position.

10 CFR 34.31, Training, is the section that addresses the training of radiographers. It is fairly specific in content and time requirements.

DOE/EH-0256T (Revision 1), *Radiological Control Manual*, offers detailed guidance for implementation of radiation protection in the DOE system. It establishes practices for the conduct of DOE radiological control activities, states DOE's position and view on the best course of action currently available in the area of radiological controls, and states that the site-specific radiological control manual should incorporate ANSI N 43.2 and N 43.3. It also states that management and the radiological control organization should establish control requirements for incidental devices like electron beam welders and electron microscopes, which are not addressed by any of the above standards. The manual states that DOE facilities should follow the requirements in 10 CFR 34. It mentions that offsite subcontractors performing radiography work onsite must have a valid NRC or Agreement State license. Regarding training, the manual states that radiographers and operators of RDGs should be trained in accordance with the requirements found in 10 CFR 34.31.

NOTE: Statements made in the *Radiological Control Manual* are now considered recommendations, not mandatory requirements, unless the contractor has committed to specific items in their contractual agreement with DOE. The manual is intended to be reissued as a technical standard. The use of "shall" statements presently in the document will presumably be changed to "should" statements.

3. SELF-STUDY SCENARIOS/ACTIVITIES AND SOLUTIONS

Scenario 1

A repairman and an operator were recently exposed to x-rays from an analytical device used in the spectrographic analysis of metal at a DOE facility. The device was an enclosed-beam x-ray system. In order to facilitate a repair on the filter holder, a lead beam stop that was part of a multiple sample holder device had been removed. This beam stop is mechanically difficult to remove and is, therefore, not interlocked. As the repairman was making a telephone call from across the room, the operator entered the room and turned on the x-ray unit. The repairman then returned to work on the filter holder. Over the course of the next 3 to 10 seconds, the repairman inadvertently touched the cooling jacket of the x-ray tube and felt a warm sensation. He immediately realized that the x-ray tube was on and terminated the exposure. During this time, the operator was located approximately one meter from the port. The operator immediately reported this occurrence as a radiation incident to his supervisor.

Describe the hazards to the repairman and the operator. List some follow-up actions to this incident that should be taken by the supervisor and contractor management. Briefly identify the applicable standard(s) and evaluate the incident in relation to requirements of the standard(s).

Scenario 1, Solution
(Any reasonable paraphrase of the following is acceptable.)

Hazards to the repairman involve exposure to the fingers and hands. Because he was very close to the beam while it was on, it is very likely that his fingers or hands could have actually been in the beam for a short time. The repairman may suffer some acute effects of radiation exposure to his fingers and hands, as well as be at risk for cancer in the area exposed. The operator was standing about one meter away from the beam. He may or may not have received an exposure, depending on the configuration of the system. If exposed, it is likely that only a portion of his body was exposed, since the leakage or scatter beams (the main sources of exposure) would be fairly small in diameter. The operator is probably not going to suffer any acute effects, and his risk of long-term effects will depend on the level of exposure.

Some of the follow-up actions that should be taken by the supervisor and contractor management include:

- Immediately process any personnel monitoring devices that the workers were wearing. The dosimetry processor should be notified of the energy range of the x-rays that may have caused the exposure.
- Interview both workers to determine exactly what happened, in what sequence, and when. The workers should be asked to retrace their movements to the best of their knowledge. It is important that this action be performed as soon as possible after the incident so that the workers' memories are still fresh. It is helpful for two interviewers to document the workers' stories so that discrepancies can be resolved before a final report is written.
- Enact a time-motion study of the workers' actions. Once this has been accomplished, management should obtain radiation exposure measurements to assess worker dose. The measurements should be made with an instrument capable of measuring high exposure rates of low-energy x-rays. Corrections may also need to be made to the instrument reading if the detector chamber is large relative to the size of the beam.
- Refer the workers for medical follow-up. Dosimeter results or radiation measurements may be helpful to the examining physician.
- Evaluate the incident from a management perspective relative to regulatory requirements, notifications, root cause, ALARA, and prevention of future similar incidents.

The most pertinent standard is ANSI N43.2, *Radiation Safety for X-Ray Diffraction and Fluorescence Analysis Equipment*. Probably the most significant deviation from requirements of the standard involves a procedural requirement to ascertain that the tube is off before performing maintenance or modifications. Section 6.5.1 of the standard states, "No operation involving removal

of covers, shielding materials, or tube housings; or modifications to shutters, collimators, or beam stops shall be performed without ascertaining that the tube is off and will remain off until safe conditions have been restored. The main switch, rather than safety interlocks, shall be used for routine shutdown in preparation for repairs." Both the repairman and the operator failed to pull the main power switch before repairs.

Section 5.2.2.1.4 requires a visual indicator (light) at the switch as well as at the tube housing. There may have been a visual indicator, but if so, it is unclear why the repairman would not have seen it before resuming repair work. Instead, he realized the beam was on by accidentally touching the cooling jacket of the tube. A visual indicator at the tube housing may have prevented his fingers and hands from receiving an unnecessary exposure.

Once dosimeter results are available, a dose assessment can be performed on the workers. The dose assessment should be based on both the dosimeter results and the incident reconstruction data. Dose assessments will indicate if dose limits were exceeded.

4. SUGGESTED ADDITIONAL READINGS AND/OR COURSES

Readings

- ANSI N 43.2-1988, *Radiation Safety for X-Ray Diffraction and Fluorescence Analysis Equipment*.
- ANSI N 43.3-1993, *General Safety Standard for Installations Using Non-Medical X-Ray and Sealed Gamma Ray Sources Energies Up to 10 MeV*.
- 10 CFR 34, *Licenses for Radiography and Radiation Safety Requirements for Radiographic Operations.*
- DOE/EH-0256T (Revision 1), *Radiological Control Manual*.
- DOE Order 5480.4, *Environmental Protection, Safety and Health Protection Standards.*
- G-10 CFR 835/C3 (Revision 1), *Radiation-Generating Devices*.
- Lubenau, Joel O., et al. (1969). *Analytical X-ray Hazards: A Continuing Problem*. Health Physics, Vol. 16, pp. 739-746.
- Weigenburg, Irving J., et al. (1980). "Injury Due to Accidental Exposure to X-rays from an X-ray Fluorescence Spectrometer." *Health Physics*, Vol. 39, pp. 237-241.

Courses

- *Applied Health Physics* -- Oak Ridge Institute for Science and Education.
- *Radiation Protection Functional Area Qualification Standard Training* -- GTS Duratek.